UE-Group Based Multi-beams Subchannel Assignment for mmWave Cellular Networks (Invited Paper)

Zhongjiang Yan[1,2](✉), Mao Yang[1], Bo Li[1], Yusheng Liang[1], and Xiaoya Zuo[1]

[1] Northwestern Polytechnical University, Xi'an 710072, China
{zhjyan,yangmao,libo.npu,zuoxy}@nwpu.edu.cn

[2] Science and Technology on Communication Networks Laboratory, Shijiazhuang 053200, China

Abstract. In millimetre cellular wave (mmWave) networks, beamforming is an enabling technology. Although the beams in mmWave network are directional and in narrow shapes, there may also exist overlapped areas. To enable the multi-user simultaneous transmissions within the same time slot, the multi-beams subchannel assignment problem is formulated as a non-linear integer programming problem. To combat the complexity, a UE-group based subchannel assignment algorithm is proposed in this paper. According to the locations of the UEs' in the overlapped areas, or the non-overlapped areas, the subchannels are assigned to the UE/UEs, where the beam spatial reuse gain and subchannel multi-user diversity gain are both exploited. Simulation results evaluate the performance of the proposed algorithm, and reveal the relationships of the beam spatial reuse gain and subchannel multi-user diversity gain, with the UE numbers and the downlink traffic load of each UE, respectively.

Keywords: mmWave · Multiple beams · UE-group

1 Introduction

For the 5G applications, such as Internet of Things, Virtual Reality, etc., millimetre wave (mmWave) wireless communication technology is a promising proposal to meet the increasing mobile users demand on high data rate [1]. To combat the high path loss of mmWave, the large scale array is employed to form several directional and narrow shape beams to serve the multiple users. However, there may also exist overlapping area between multiple beams. How to design an efficient resource allocation algorithm for such a multiple beams communication system is a significant and challenging problem.

Due to the high transmission rate of each beam in the mmWave systems, multi-user transmission is desired in mmWave systems, and the mmWave channel can be modelled as a frequency selective steering channel [2]. Multicarrier

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transmission technique, such as orthogonal frequency division multiple (OFDM), has been well established due to its advantages, mainly its robustness in multipath fading channels and the adaptivity in resource allocation. Particularly, when multi-user access is desired OFDMA can be applied. Thus the multiple beams resource allocation problem can be transformed as a multi-beams subchannel assignment problem.

In the literature, most of the related works on MIMO-OFDM resource allocation are on digital beamforming, such as [3–5] and the references therein. Ref. [3] considers to use joint spatial division and multiplexing method to mmWave channels, where clusters of multi-path components are used to serve several users. A conflict graph based method is proposed to select users and allocate the angular. Ref. [4] investigate the downlink massive MU-MIMO transmission with multiple antennas at each user, and a beam domain channel model is proposed. By selecting users with non-overlapping beams, the MU-MIMO channels are decomposed into multiple single user MIMO channel links. Ref. [5] considers to use coordinated/switched beamforming to serve the UEs' demand while avoiding interference across sectors, where the beam patterns among the base stations are scheduled. For the mmWave resource allocation problems, most of the related works study the problems in the wireless personal area networks or WLAN. For example, Ref. [6] considers the time spatial resource allocation problem to serve a mixed set of multimedia applications. A channel time allocation partial swarm optimization algorithm is proposed. We have studied how to concurrently schedule multiple links in one time slot in [7], and a heuristic clique based scheduling algorithm is proposed.

To the best knowledge of the authors, this paper is the first to study how to design a multiple beams subchannel assignment algorithm, to exploit both the beam spatial reuse gain[1] and the subchannel multiple user diversity gain[2]. The main contributions are three folds.

– The multiple beams subchannel assignment problem is formulated as a non-linear integer programming problem.
– To combat the complexity of finding the optimal solution, a UE-group based multiple beams subchannel assignment algorithm is proposed, to exploit both the beam spatial reuse gain and the subchannel multi-user diversity gain.
– Simulation results evaluate the performance of the proposed algorithm, and reveal the relationships of the beam spatial reuse gain and subchannel multi-user diversity gain, with the UE numbers and the downlink traffic load of each UE, respectively.

[1] Suppose beam b_1 and b_2 share the same frequency, pointing to different directions. User n_1 and n_2 are covered by b_1 and b_2, respectively. Then user n_1 and n_2 can share the same subchannel of b_1 and b_2 at the same time. This is referred as the beam spatial reuse gain.

[2] For a given subchannel, different users may have different data rate on it, and when the user with highest data rate is selected then this selection bring a gain which is the subchannel diversity gain.

Section 2 present the system model, and formulate the subchannel-beam-UE assignment problem as a non-linear integer programming problem. Section 3 details the proposed UE-group based multiple subchannel assignment algorithm. The performance of the proposed algorithm is evaluated in Sect. 4. Section 5 concludes this paper.

2 System Models

Suppose there are B beams with fixed pointing directions fully covering a given sector of a mmWave small cell, where there are N UEs randomly distributed. Each UE associates with one beam according to its received SINR. All of the B beams are working on the same frequency channel in OFDMA mode, which is composed of K subchannels.

In the following, we use n, b, k to denote a specific UE, beam and subchannel, respectively. Let the binary matrix $\mathbb{A} = [a_{b,n}]_{B\times N}$ denote the association relationships between the UEs and the beams, where $a_{b,n} = 1$ meaning that the UE n is associated with beam b. In this paper, we assume each UE can only associate with only one beam, i.e., $\sum_{b=1}^{B} a_{b,n} \leq 1$. Furthermore, each beam can only assign its subchannels to the UEs associated with it. Let $\mathcal{B}_i^j$ denote the jth set of any i beams out of B, where $1 \leq j \leq C(B,i) = \frac{i!}{B!(B-i)!}$, and $1 \leq i \leq B$. And let $\mathcal{N}_{\mathcal{B}_i^j}$ denote the set of UEs covered by all of the beams in $\mathcal{B}_i^j$.

The path loss of mmWave is given as $PL[dB] = \alpha + 10\beta\log_{10}(d) + X_\sigma$, where d is the distance between transmitter and receiver, α is the intercept in dB, β is the slope, and X_σ is a zero mean Gaussian random variable with a standard deviation σ in dB. To decrease the large path loss impact, beamforming is employed by the antenna array, where the beams can point to different directions by changing the current of arrays. In this paper, the rectangular plane array is employed which are arranged in a rectangular grid unit in the XOY plane [8]. Beam b's transmitter antenna gain at UE n can be computed as $G_t(b,n) = [S_{norm}(b,n)]^2 G_{t_{max}}$, where $S_{norm}(b,n)$ is normalized array radiation factor received by UE n from beam b, and $G_{t_{max}}$ is the maximum transmitter antenna gain of beam b.

UE n's received power from beam b can be calculated as $P_r(b,n)[dBm] = P_t[dBm] + G_t(b,n)[dBi] + G_r[dBi] - PL[dB]$, where P_r and P_t are the received and transmitted power, respectively. At a given time slot, by taking the small-scale Rayleigh fading into account, the received signal power at subchannel k can be written as $P_r(b,n,k)[mw] = \frac{P_r(b,n)[mw]}{K} \times Y_\delta$, where Y_δ is a Rayleigh distributed random variable with parameter δ. Then, the received signal to interference plus noise ratio (SINR) from beam b for UE n in subchannel k can be calculated. And the data rate of UE n in subchannel k of beam b can be got from the SINR-CQI mapping table.

Since future wireless networks are expected to be designed for data applications with high and flexible data rates especially in the downlink, the investigations concentrate on downlink transmission. The BS holds the UEs' downlink traffic and want to transmit them to the UEs with the maximum network throughput. Let $\mathcal{R} = \{R_n, 1 \leq n \leq N\}$ denote the downlink traffic rate requirement set of the UEs, where the unit of R_n is bits per second (bps). Then, the proposed subchannel-beam-UE assignment problem can be formulated as follows

$$\max \sum_{n=1}^{N} \min \left(\left(\sum_{b=1}^{B} \sum_{k=1}^{K} a_{b,n} x_{b,k,n} r_{b,k,n} \right), R_n \right) \tag{1a}$$

$$s.t. \sum_{n=1}^{N} x_{b,k,n} \leq 1, \text{where } x_{b,k,n} = \{0, 1\}, \tag{1b}$$

$$\sum_{b=1}^{B} \sum_{k=1}^{K} x_{b,k,n} r_{b,k,n} \geq R_n. \tag{1c}$$

In (1a), the objective of the formulated problem is to maximize the sum of the total users' assigned data rate, which is the minimum of each user's assigned data rate and its required downlink data rate. To avoid the co-subchannel interference between UEs, a given sub-channel of one beam can not assigned to more than one UE, and thus we have (1b), where $x_{b,k,n}$ is a binary variable and $x_{b,k,n} = 1$ indicating that the subchannel k of beam b is assigned to UE n. The assigned subchannels to UE n can not be smaller than its traffic load R_n as shown in (1c).

We note that the formulated problem (1a–1c) is a non-linear integer programming problem, which is always an NP-hard problem. Due to space limitation, the proof is omitted. Next, we focus on designing a heuristic algorithm to solve the proposed problem in the following section.

3 A UE-Group Based Multiple Beams Subchannel Assignment Algorithm

In this paper, a UE-group based multiple beams subchannel assignment algorithm is proposed. The basic idea is to divide the UEs into groups firstly according to the beams' overlapped coverage areas or non-overlapped coverage areas. Then, the subchannels are assigned to the UEs to exploit the beam spatial reuse gain and the subchannel multi-user diversity gain.

3.1 Dividing the UEs into Groups

The terms of *non-overlapped areas of beams* and *overlapped areas of beams* are illustrated in an example, as shown in Fig. 1. UE 2 and UE 3 are located in the overlapped area of Beam 1 and Beam 2, and UE 1 is located in the non-overlapped area of Beam 1, and UE 4 and UE 5 are located in the non-overlapped area of Beam 2. Therefore, when there are 2 beams the total UEs can be divided into 3 UE-groups.

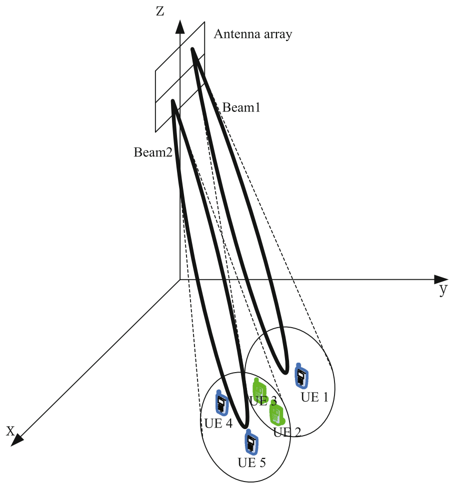

Fig. 1. Example of overlapped areas of beams

In the practical mmWave cellular networks, the measured SINR in each subchannel of beams, or the mapped data rate, i.e., $r_{b,n,k}$, can be used to divide the UEs into groups. In this paper, if $\max_{1 \leq k \leq K} r_{b,n,k} \geq \gamma$, then UE n is covered by beam b, where γ is the lowest data rate corresponding to the minimum CQI. The physical meaning is that if the data rate of beam b's highest data rate of the subchannels is larger than γ, then at least one of the subchannels of beam b can be assigned to UE n.

3.2 The Proposed Algorithm

We note that the beam spatial reuse gain can be achieved by assigning the subchannel to the UE/UEs located in the non-overlapped areas. While the subchannel multi-user diversity gain is achieved by assigning the subchannel to the UE which has the highest data rate. To jointly exploit the both gains, the UE-group based multi-beams subchannel assignment algorithm is proposed, and the pseudo-code of the proposed algorithm is given in Algorithm 1.

To avoid deep shadowing effect of the subchannels, the subchannel assignment sequence is randomly selected in each time when the proposed algorithm is run. Each subchannel is assigned sequentially. The inputs include the association relationship matrix of the UEs and the beams, i.e., $\mathbb{A}$, the data rate matrix of the UEs at each subchannel of each beam, i.e., $\mathbb{R}$, the set of downlink traffic requirements of the UEs, i.e., $\mathcal{R}$, and the non-overlapped UE-groups and the overlapped UE-groups $\{\mathcal{N}_{\mathcal{B}'} | \forall \mathcal{B}' \subseteq \mathcal{B}\}$. The output is the assignment binary variable matrix $\mathbb{X}$.

To exploit both the beam spatial reuse gain and the subchannel multi-user diversity gain, each subchannel k's two data rates is computed firstly, which is given by both that of the non-overlapped UE-groups, r_{ng}, and that of the overlapped UE-groups r_{og}. For the non-overlapped UE-groups, subchannel k's data rate is the sum of the maximum data rate of each non-overlapped UE-group, exploiting the beam spatial reuse gain. From line 4 to line 11, the data rate of the non-overlapped UE-groups at subchannel k is calculated as r_{ng}, and the set of UEs which can bring the data rate are presented as $\mathcal{N}_{ng}$. While for the overlapped UE-groups, subchannel k's data rate is the maximum of each overlapped UE-group's maximum data rate, without beam spatial reuse gain. From line 12 to 19, the data rate of the overlapped UE-groups is calculated as r_{og}, and the UE which can bring the data rate is presented as n_{og}. Next, the subchannel k is assigned to the UE/UEs which can bring the maximum data rate,

Algorithm 1 . UE-Group based Multiple Beams Subchannel Assignments Algorithm

Require: $\mathbb{A} = [a_{b,n}]_{B\times N}, \mathbb{R} = [r_{b,k,n}]_{B\times K\times N}, \mathcal{R} = \{R_n | 1 \le n \le N\}, \{\mathcal{N}_{\mathcal{B}'} | \forall \mathcal{B}' \subseteq \mathcal{B}\}$, where $\mathcal{B} = \{b_i | 1 \le i \le B, b_i \text{ is a beam}\}$
Ensure: $\mathbb{X} = [x_{b,k,n}]_{B\times K\times\ N}$
1: $\mathcal{K} = \{1, 2, \cdots, K\}$, $\mathcal{N} = \{1, 2, \cdots, N\}$, $\mathbb{X} = [x_{b,k,n}]_{B\times K\times\ N} = zeros(B, K, N)$;
2: **while** $\mathcal{K} = \emptyset$ or $\mathcal{N} = \emptyset$ **do**
3: randomly select a k from $\mathcal{K}$, $\mathcal{K} = \mathcal{K} - \{k\}$;
4: $r_{ng} = 0$, $\mathcal{N}_{ng} = \emptyset$;
5: **for** b from 1 to B **do**
6: $r_{max} = 0$, $n_{max} = -1$;
7: **for** $\forall n \in (\mathcal{N}_{\{b\}} \cap \mathcal{N})$ **do**
8: **if** $r_{max} < (a_{b,n} r_{b,k,n})$ **then**
9: $r_{max} = r_{b,k,n}$, $n_{max} = n$;
10: **if** $n_{max} \neq -1$ **then**
11: $r_{ng} = r_{ng} + r_{max}$, $\mathcal{N}_{ng} = \mathcal{N}_{ng} + \{n_{max}\}$;
12: $r_{og} = 0$, $n_{og} = -1$;
13: **for** $\forall \mathcal{B}' \subseteq \mathcal{B}$, where $|\mathcal{B}'| \ge 2$ **do**
14: $r_{max} = 0$, $n_{max} = -1$;
15: **for** $\forall n \in (\mathcal{N}'_{\mathcal{B}} \cap \mathcal{N})$ **do**
16: **if** $r_{max} < (a_{b,n} r_{b,k,n})$ **then**
17: $r_{max} = r_{b,k,n}$, $n_{max} = n$;
18: **if** $n_{max} \neq -1$ and $r_{og} > r_{max}$ **then**
19: $r_{og} = r_{max}$, $n_{og} = n_{max}$;
20: **if** $r_{ng} > r_{og}$ **then**
21: **for** $\forall n \in \mathcal{N}_{ng}$ **do**
22: $x_{b,k,n} = 1$, $R_n = R_n - r_{b,k,n}$;
23: **if** $R_n \le 0$ **then**
24: $\mathcal{N} = \mathcal{N} - \{n\}$;
25: **else**
26: **if** $r_{og} > 0$ **then**
27: $x_{b,k,n_{og}} = 1$, , $R_n = R_n - r_{b,k,n_{og}}$;
28: **if** $R_n \le 0$ **then**
29: $\mathcal{N} = \mathcal{N} - \{n_{og}\}$;
30: **return** $\mathbb{X}$;

exploiting the subchannel multi-user diversity gain. If $r_{ng} > r_{og}$, subchannel k is assigned to the UE set $\mathcal{N}_{ng}$ from line 21 to line 24, and the downlink traffic loads of the UEs in $\mathcal{N}_{ng}$ are updated. The satisfied UE/UEs will not run for more subchannels.

4 Performance Evaluation

To evaluate the performance of the proposed algorithm, we compare it with a heuristic method, which exploit the subchannel multi-user diversity gain first, and then exploit the beam spatial reuse gain. In the simulation, the number of the antennas is set as 16×16, where 4 beams are formed according to [8]. The channel bandwidth is set as 500 MHz, with the center frequency 28 GHz, which is divided into 32 subchannels in OFDM mode. In each subchannel the noise power can be calculated as $P_N = 6.425 \times 10^{-11}$ mW. The channel model parameters are set as $\alpha = 45.3, \beta = 2.9, \delta = 0.04$. The height of BS antenna arrays is 10 m, and the height of UE antenna is 1.5 m. The radius of a sector is 50 m with angle $60°$.

The simulation results are demonstrated in Figs. 2 and 3. In Fig. 2, the requirement of each UE, R_n, increases from 50 Mbps to 350 Mbps with a step of 50, and then increases from 350 Mbps to 950 Mbps with a step of 100. And for each setting of R_n, the scenarios of UE number with 30, 60 and 90 are simulated. For the proposed method, the network throughput increases as R_n increases. While for the heuristic method, the networks throughput first increases and then decreases as R_n increases. Furthermore, it can be seen that there is a peak rate achieved by both the proposed method and the heuristic method. This can be explained as follows. When R_n is small, with the heuristic method the requirement of the UEs located in the overlapped area can be satisfied and a few of subchannels can be left, which can be used by the UEs located in the non-overlapped area. However with the increase of R_n, the number of the left subchannel goes to zero, which made the network throughput decreases. It can be seen that the lowest network throughput of the heuristic method is near 2.7 Gbps, which is almost equivalent to (32×86.79 Mbps), where 86.79 Mbps is the highest data rate achieved by one subchannel. In other words, the subchannel multi-user diversity gain is high when R_n is small, while when it is large the gain is low. This is also the reason that why there is a pulse with the proposed method when R is small. In Fig. 3, the number of UEs increases from 10 to 90 with a step of 10, under different download requirements of each UE. It can be found that the cures are similar with Fig. 2. And it can be concluded that when the UE number is small the multi-user diversity gain is high, while when as the increase of the UE number the multi-user diversity gain decrease.

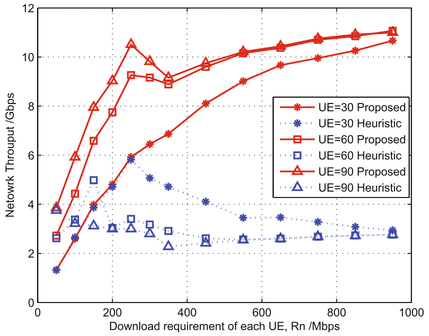

Fig. 2. Network throughput with various R_n

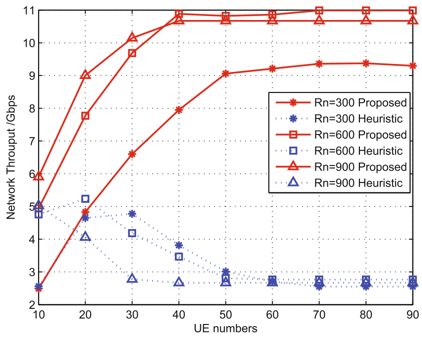

Fig. 3. Network throughput with various UE numbers

5 Conclusion

Beamforming is a promising technology to enable the mmWave network. How to assign the subchannels of multi-beams to multi users is studied in this paper, which is formulated as an integer programming problem. To combat the complexity, a UE-group based subchannel algorithm is proposed, to explore both the beam spatial reuse gain and the subchannel multi-user diversity gain. Simulation results evaluate the performance of the proposed algorithm. And it shows that the beam spatial reuse gain will increase with the increase of the download requirement of each UE and the UE numbers. However, the subchannel multi-user diversity gain will increase with the increase of the download requirement of each UE and the UE number, when they are small. However, it will decrease with the increase of the download requirement of each UE and the UE number, when they are large. Further characterizations of the beam spatial gain and the subchannel multi-user diversity gain will be studied in the future.

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